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04 May 2023

EUDEM2

The EU in Humanitarian Demining-State of the Art on HD Technologies, Products, Services and Practices in Europe

IST–2000-29220

Technology Survey Final Report
D15
WP4 Technology Survey

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Project Co-ordinator:	VUB
Partners:	VUB, EPFL and TUG.

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Executive Summary

This Deliverable summarizes the EUDEM2 activities within WP4 – *Technology Survey* supported by WP7 Workshop Organization & Reporting (D20-D21, D22) and WP6 Interviews (D18, D19). The evolution of the Technology Survey activities during the three phases of the project is briefly sketched in the Introduction (Section 1).

During the first phase of the project, the EUDEM2 partners have mostly concentrated on their respective fields of interest and expertise, in particular the *Metal Detector Patent Study* and its recent full revision, the studies on *EM Methods in Geophysics*, on *Electrical and Magnetic Properties of Soil*, on the *Determination of Spatial Variability of Soil Conductivity*, and on *Acoustic Methods*. The corresponding results are described in Section 2.

The second and third phase of the project, described in Section 3, have seen increased emphasis on the understanding of the *past/current R&D projects* (EC co-funded and National ones), and in particular on synergies between the projects. The corresponding project descriptions and Organigrams are introduced as well.

Section 4 deals with the "*Catalogue of Advanced Technologies for HD*". This *Catalogue* summarizes to our opinion the main technological achievements of the last years. It is similar in concept to those already released by GICHD on metal detectors and mechanical systems, as well as to the RAND report. Work on this *Catalogue* has started during the second half of 2003, with discussions on the requirements and methodology, as well the results' form.

Section 5 deals with the structuring and analysis of the data collected from the Field Survey (D19) with the objective of producing the survey results, including a summary of the collected data and the corresponding analysis, as well as a "*Catalogue of Demining Technologies in Field Use".*

Content

1 Introduction

1.1 Technology Survey Objectives

One of the main aims of EUDEM2 is to carry a broad scope technology survey on technology which is potentially interesting for Humanitarian Demining. The technology survey activity has been carried out worldwide, through literature analysis, direct contacts (interviews and field visits) and participation to international workshops and conferences.

After the first Advisory Panel meeting and the first annual review, it was decided:

- That the main focus should be towards the *technology developers*,
- To *stick to the sensor developments*,
- To detail the *status of past/current R&D project*: with a *particular focus on* EC co-funded projects and National projects.

As a consequence, the requirements of the Technology Survey Work Package, which were mainly contained in the originally planned project's Milestone 6 and 7 (see also *D14-Technology Survey Intermediate Report*), have been modified as follows:

- **M6** Technology Survey Intermediate Results (month 24):

  This Milestone has been changed to *D14-Technology Survey Intermediate Report* as the focus of the Technology Survey has been refined taking into account the project's Advisory Panel input, and the Reviews of the first and second year. (Agreement from EC services on A106788.)

- **M7** Technology Implementation Plan **(D13)** (m34) – Results:

  This Milestone has been revised according to the new M6. It will contain a *Catalogue* providing a comprehensive and technically motivated overview of the potentials of each technology studied.

In practice the following EUDEM2 Technology Study concept has been proposed and accepted:

- **Initial phase – up to end 2002 (first year):**

  The project's partners will concentrate in particular on their respective fields of interest and expertise, e.g. MD, soil response, Geophysics, Acoustic, R&D in Central/Eastern Europe.

- **Second Phase – 2003**:
  - Overview of technology development via *EUDEM2-SCOT conference*,
  - Restrict the choice to a few technologies of interest, and develop the concept of a *Catalogue*,

- Deepen the understanding of the *past/current R&D projects* (EC co-funded and National),
- Prepare Deliverable D14 "Technology Survey Report 1" at month 18.

- **Third Phase – end of project**:
  - Finalize overview of past/current R&D projects,
  - Finalize technology *Catalogue*,
  - Prepare final workshop,
  - Prepare Technology Implementation Plan (M7).

After the EUDEM2 conference (September 2003), we noticed a lack of quantitative and qualitative analyses of technologies in use in the field. As a consequence we added to the technology survey a *Field Survey* with the aim of collecting information on technologies in use. The focus of the study has been on technologies in use and operational aspects, including application/use conditions, costs, etc. Moreover, we tried as well to derive some requirements for Mechanical systems. This study has been conducted with the support of the University of Genova, Italy.

In summary the third phase of the Technology Survey consisted of:

- Finalize overview of past/current R&D projects,
- Finalize technology *Catalogue*, including 'in use' technologies,
- Finalize the acoustic study,
- Analyse the collected Field Survey data,
- Prepare the EUDEM2 Final Workshop,
- Prepare Technology Implementation Plan (M7).

1.2 Related Documents

As mentioned above the studies carried out during WP4 cover the following aspects:

- Technology Studies,
- EC co-funded and National Projects,
- *Catalogue* of Advanced Technologies for HD,
- Field Survey.

Each of the studies resulted in one or several documents, which have been made available under the EUDEM2 web site. The following table lists all the studies reports. All these documents should be considered as Annexes to this Deliverable.

Report Topic	Title	Authors	Date
Technology Studies	Humanitarian Demining related RTD in Central and Eastern Europe	J. Wtorek, A. Zduniak, H. Jonas	October 2003
Technology Studies	Determination of Spatial Variability of Soil Conductivity	J. Wtorek, J. Wyszy, A. Zduniak	October 2003
Technology Studies	Electrical and Magnetic Properties of Soil	J. Wtorek	October 2003
Technology Studies	Metal Detectors for Humanitarian Demining: a Patent Search and Analysis, v 2.0	C. Gaudin, C. Sigrist, C. Bruschini	November 2003
Technology Studies	Electromagnetic Methods in Geophysics	J. Wtorek, A. Bujnowska	October 2004
Catalogue of Advanced Technologies for HD	Catalogue of Advanced Technologies and Systems for Humanitarian Demining	S. Crabbe, C. Bruschini, H. Sahli	November 2004
Field Survey	Field Survey Results	E. E. Cepolina, C. Bruschini, K. De Bruyn	November 2004
Field Survey	Catalogue of Demining Technologies in Field Use	E. E. Cepolina, C. Bruschini,	November 2004
Technology Studies	(Non-Linear) Acoustic Landmine Detection Study	F. Bellan, A. Bulletti, L. Capineri, C. Bruschini	November 2004
EC co-funded and National Projects	Study of Demining Related R&D in France	E. Crescenzo, C. Bruschini	November 2004

2 Technology Studies

This section describes the studies and related reports undertaken by the partners in their field of expertise.

2.1 Metal Detectors Patent Study

The **"Metal Detector Patent Search and Analysis"** was distributed and revised a first time during the first year of the project. It is a collection of a large number of patents (>60 main ones, >100 in total) on metal detectors, the most diffused sensor for HD applications, and for which patents represent a valuable source of (technical) information. It includes an analysis of the main ones.

All patents are available online (http://www.eudem.info/ → Search: "patent") as PDF files linked from the main document. A CD-ROM version, which also contains all patents, is available upon simple request from the EUDEM2 help desk.

Improvements with respect to v1

The second revision (2003) of this report represents a major improvement with respect to the previous releases:

1. A large number of patents (nearly 200) have been added. About 20 of them are directly related to Metal Detectors (for demining applications) and have been added to the overview in Chapter 5.

2. All patent related information has been collected in a database system in order to facilitate data entry, data extraction, report generation and searching.

3. The report presents also in its Annex improved general information about the European patents system and the Patent Co-operation Treaty (PCT) as well as the patent numbering systems.

The second revision has also been made available on CD-ROM and on the EUDEM2 Website (Dissemination & Exploitation Task), much like the previous releases. The CD-ROM was again distributed upon simple request.

2.2 EM Methods in Geophysics

The **electromagnetic (EM) geophysical methods** can be divided into **controlled-source** (artificial source of signal) and *uncontrolled* ones (natural source of signal, e.g. earth magnetic field). The review of the methods is restricted only to the former ones. Methods used in geophysics can be categorized into two groups: 1) *model-fitting* by trial-and-error, and 2) **inversion** of controlled-source electromagnetic data. The properties of the former methods are limited due to the utilization of relatively simple models involving a high degree of subjectivity when fitting them to the observed data. A more satisfactory method of interpretation is inversion where the properties of the earth are calculated directly or indirectly from the data. Inversion, which is more objective than curve fitting, also provides information on resolution

and reliability of the interpreted models. However, the arising *inverse problems* are **non-linear** and **ill-conditioned**, i.e. they are very sensitive to noise and their solution time consuming.
To date, existing algorithms can be sorted into the following four categories: a). *non-iterative linearization-based* algorithms; b). *iterative* algorithms solving the full non-linear problem; c). *layer stripping* algorithms; d). *direct* (non-iterative) algorithms. Apart from presenting the selected EM methods, the description of different approaches to solve geophysical inverse problems, applicable to demining activities, is also presented in the report.

2.3 Electrical and Magnetic Properties of Soil

Soil conductivity as well as **permittivity** depend on the *morphological structure and minerals, water, air, and biological inclusions in the soil*. As a result, the soil conductivity is considered as the conductivity of a **mixture**, e.g. as the mixture of solid sandy particles, moist clay, soil solution and air. Theoretical and empirical models of electric properties of the different components of the soil have therefore been combined into *semi-empirical mixing models*, which can be used to predict the electrical properties of the soil. The most widespread models are presented in the report.
In addition, the soil's electromagnetic parameters change **in time** and **in space**. Studies of the stochastic behaviour of the soil properties are a recent development of *soil models*. Soil conductivity can be described by its mean value, variance, probability density function and autocorrelation. However, there is *no study available* which determines the soil parameters' variability on a *scale adequate for demining procedures*.
A short survey of methods applicable to the estimation of the electromagnetic properties of soil is presented. It also contains a description of the electrical properties of biological "inclusions" present in actual soils.

2.4 Determination of Spatial Variability of Soil Conductivity

Determination of the **spatial variability** of the soil's electrical parameters acceptable in demining requires the development of adequate **measurement techniques**. It also should be applicable in the field. This report presents a study of the *spatial properties of a four-point probe* often used in geophysics or precision agriculture. It is theoretically shown how to estimate the volume of the examined soil that contributes to the measured immittance. In turn, this volume determines the possibility of data analysis in terms of their spatial variability. It is also shown how this volume depends on the probe's geometrical factors. These results are verified experimentally using a specially developed experimental stand. Moreover, the theoretical description is extended to an anisotropic case. The report also includes a short survey of four-electrode types often used in geophysical studies.

2.5 (Non-Linear) Acoustic Landmine Detection

The overall goal of this study is to identify the advantages and disadvantages (key obstacles and limits) of (non-linear) acoustic techniques applied to the landmine detection problem. In this work the collection of information available from previous studies and reports has been carried out and structured information has been produced to update the EUDEM2 web site.

Interest in this type of technique is recent and most studies and information about prototypes have been published during the last five years. The acoustic generation of seismic waves is the leading idea for new non-contact landmine detection apparatus; the effects of the interaction between the seismic waves travelling through the soil and a buried mine have been studied. The observable effect is a characteristic vibration of the mine due to its mechanical properties (particularly its compliance[1]) when excited by a seismic wave. The idea that objects "sound" in different ways has been historically exploited in many non-destructive testing techniques. The vibration of landmines or the resulting induced vibration of the soil surface have been measured by various techniques, both contact and non-contact. In some studies the results of these measurements with landmine surrogates have also been compared with theoretical models.
This study introduces and compares different methodologies and technological approaches, with the aim of helping to devise the new experiments and field tests which are necessary to validate this demining method. A comparison with other well known methods proposed and applied to humanitarian demining (metal detectors, ground penetrating radars, infrared, etc) with dedicated experiments has been started by some groups, but more work is still needed especially in the design of portable detection apparatus.

This study has in fact been carried out during the third year of the project, but has been included in this section as it is similar in nature to the other activities described therein.

[1] *Compliance*: the displacement of a linear mechanical system under unit applied force.

3 EC co-funded and National Projects

3.1 EC co-funded Projects

The objective of this study has been to give an **overview of the current European projects** (whether EC co-funded or National ones), and their **inter-relationship** (synergies), accessible from the EUDEM2 web site. The study includes for each project:

- Partners
- Project Objectives
- Time line
- Budget
- Type of sensor/system developed
- Most important results
- Degree of maturity
- Evaluation: tests where and when, and sensor(s) performance – plans for the future, ...
- Exploitation steps
- Publications.

An example of such a description is given in Figure 3-1.

DEMINE - Improved cost-efficient surface penetrating radar detector with system on chip solution for humanitarian demining (EC Funded Projects)

Start Date: 1 February 1999
End Date: 31 January 2001
Contact Person: Jürgen Sachs
Web Link: http://www-emt.tu-ilmenau.de/demine/

Project Abstract:

The Project will improve existing Anti-personnel landmine (APL) surface penetrating radar (SPR) detectors in terms of detection/false-alarm rates, cost and weight.

The main technical objectives for the improvements are:

1. Revolutionary system on chip solution based on high speed digital technology
2. Antenna array for multi-static and multi-polarisation techniques
3. Dynamic positioning measurement system
4. Multi-dimensional signal processing and classification which exploits the novel features of the radar

Objectives:

The business objectives have been identified by the industrial partners and also the research institutions, aware of their economic and competitive role for EU industry in the transition to the information society:

1. APL SPR prototype product which is practicable, affordable, valid and in demand
2. Sub-systems and Know how products which are practicable, affordable, valid and in demand for transfer into other areas of industry
3. To develop the joint-venture, investment and placement plans for A) and B)
4. To ensure effective dissemination throughout the EU for the optimal exploitation of A) and B) to enhance European industrial competitiveness as a whole.

Involved Technology Related Activities:

- Ground Penetrating Radar

Involved Organisations:

- **TU Ilmenau (Technische Universitaet Ilmenau) (prime contractor) Contact Person:** Jürgen Sachs
- AEL (Fluid Gravity / Applied Electromagnetics) **Contact Person:** Shane Cloude
- IDS (Ingegneria dei Sistemi SpA) **Contact Person:** Giovanni Alli
- MgM (Menschen gegen Minen)
- MEODAT (MEODAT Messtechnik, Ortung und Datenverarbeitung GmbH) **Contact Person:** Peter Peyerl
- QinetiQ
- VUB - ETRO (Vrije Universiteit Brussel - Department of Electronics and Information Processing) **Contact Person:** Hichem Sahli (Professor)

Related Publications:

- DEMINE Final Report

Figure 3-1 Project Description Example

The information was collected via emails, bibliography search, interviews and participation to workshops/conferences. Moreover, in order to extract the inter-relationship and synergies between the projects, the study covered the period from 1995 until today.

The study covers all the *EC co-funded projects* (see Figure 3-2), for which almost all the project descriptions have been finalized in the EUDEM2 Data Base.

3.2 National Projects

In the case of *National projects* the study aimed at:

- Defining the national **Organigram**: Who's who? Who's financing what?, and
- *Projects description*, in the same way as the EC co-funded projects.

We mainly focused on four countries: *Germany, UK, The Netherlands* and *France*, as most of the officials (ministries and research organizations) of these countries responded favourably to our request and data collection. At the end of the project the web site has been updated with respect of all the data collected for UK, The Netherlands and Germany, i.e. projects description and organigrams (see Figure 3-3, Figure 3-4 and Figure 3-5). For the French projects all the collected information has been integrated in the "Study of Demining Related R&D in France" report.

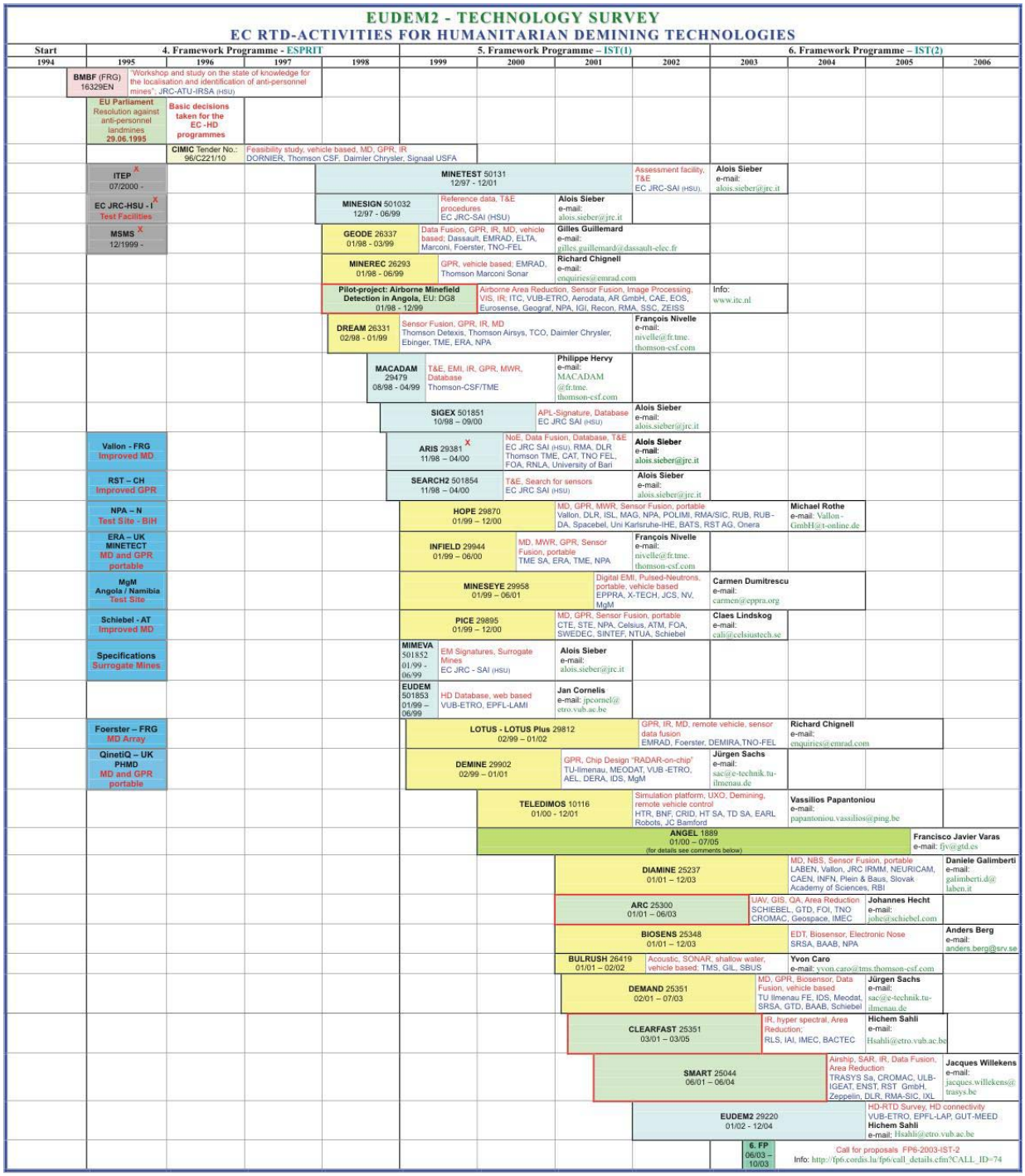
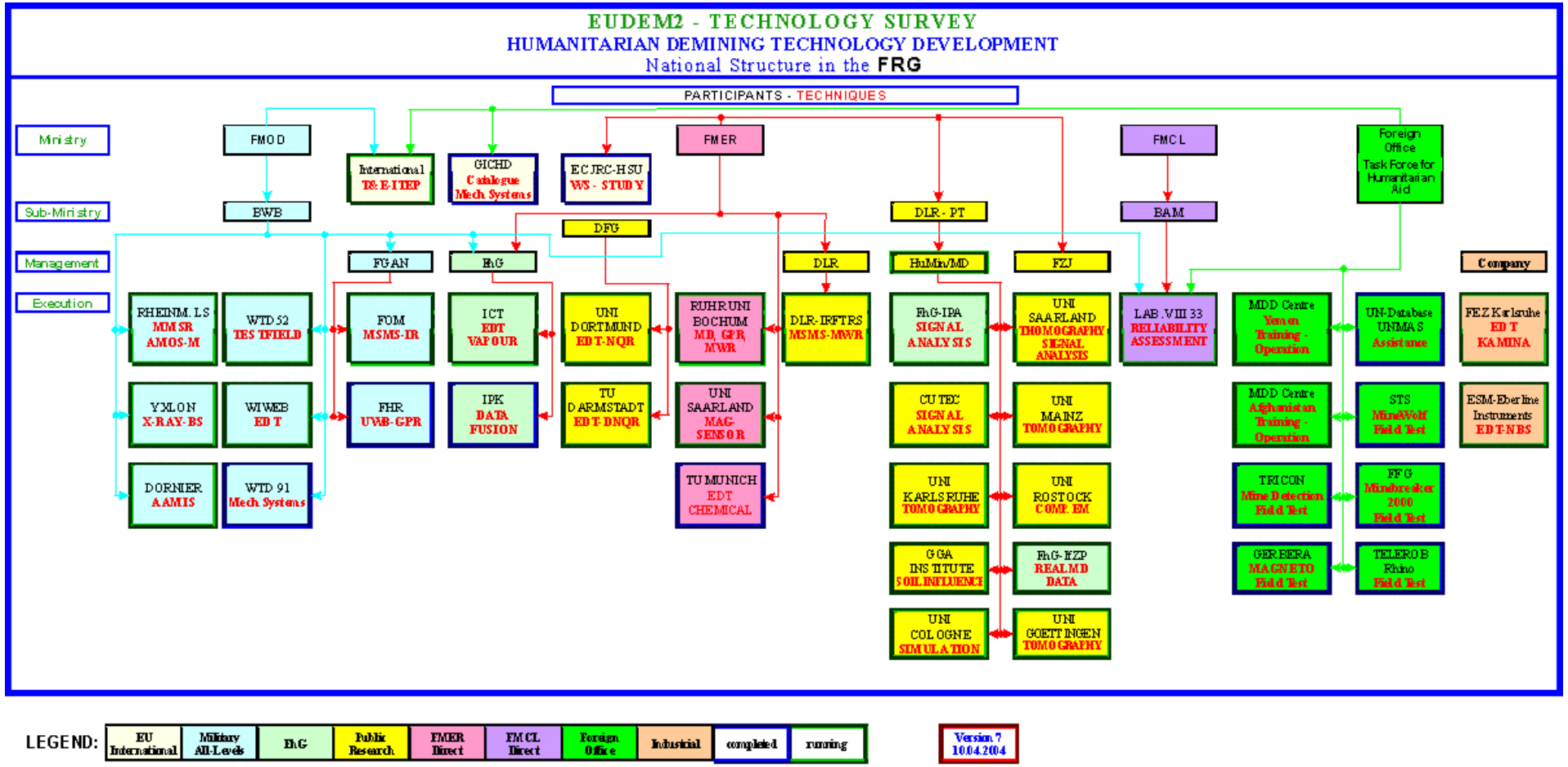


Figure 3-2 Overview of the EC co-funded projects



REMARK: This overview is showing the past and running programmes of the FRG from 1994 up to now. The structures are reflecting the constitutional federalism of the FRG.

Figure 3-3 Overview of the German National Projects (abbreviations in Table 3-1)

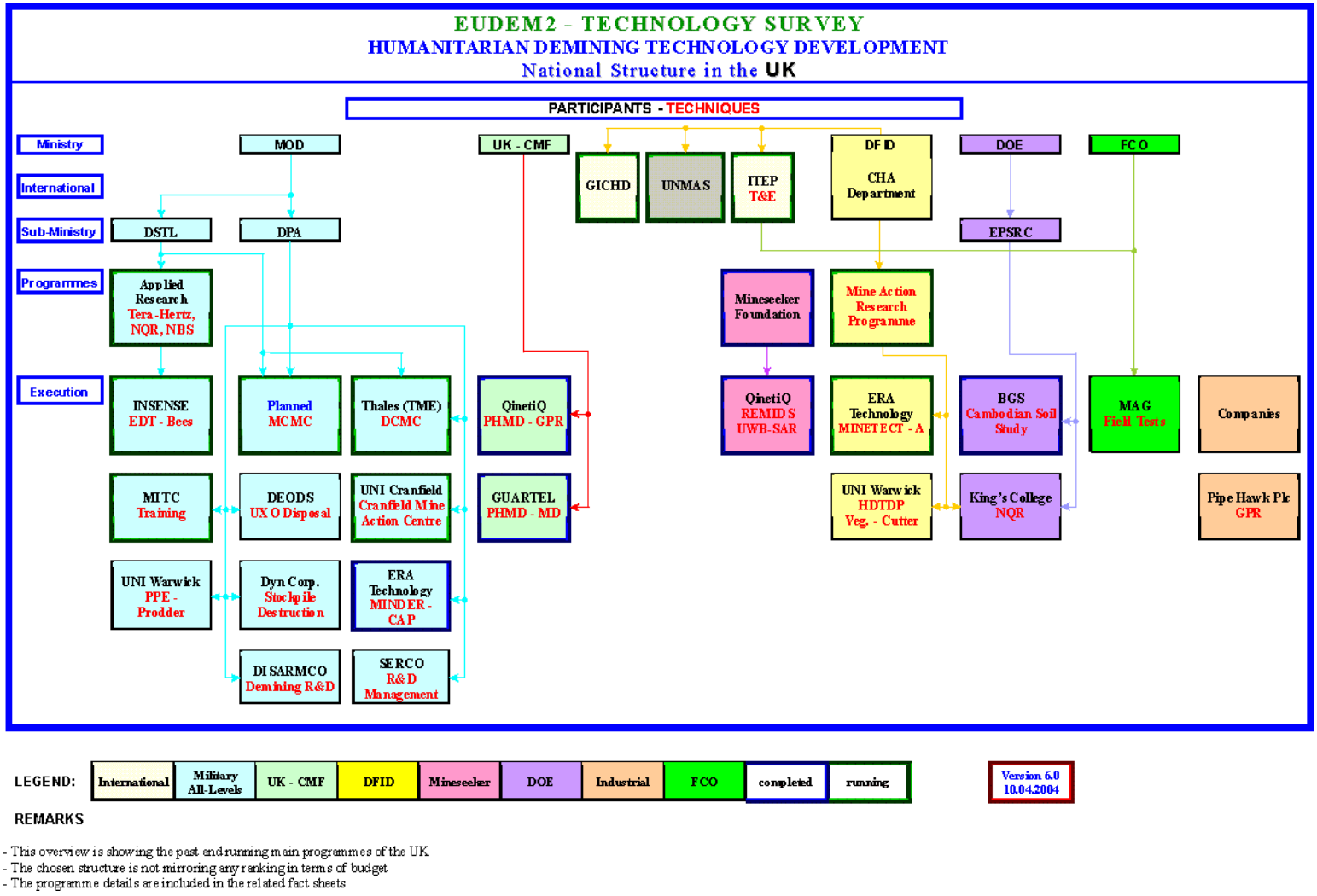


Figure 3-4Overview of the UK National Projects (abbreviations in Table 3-2)

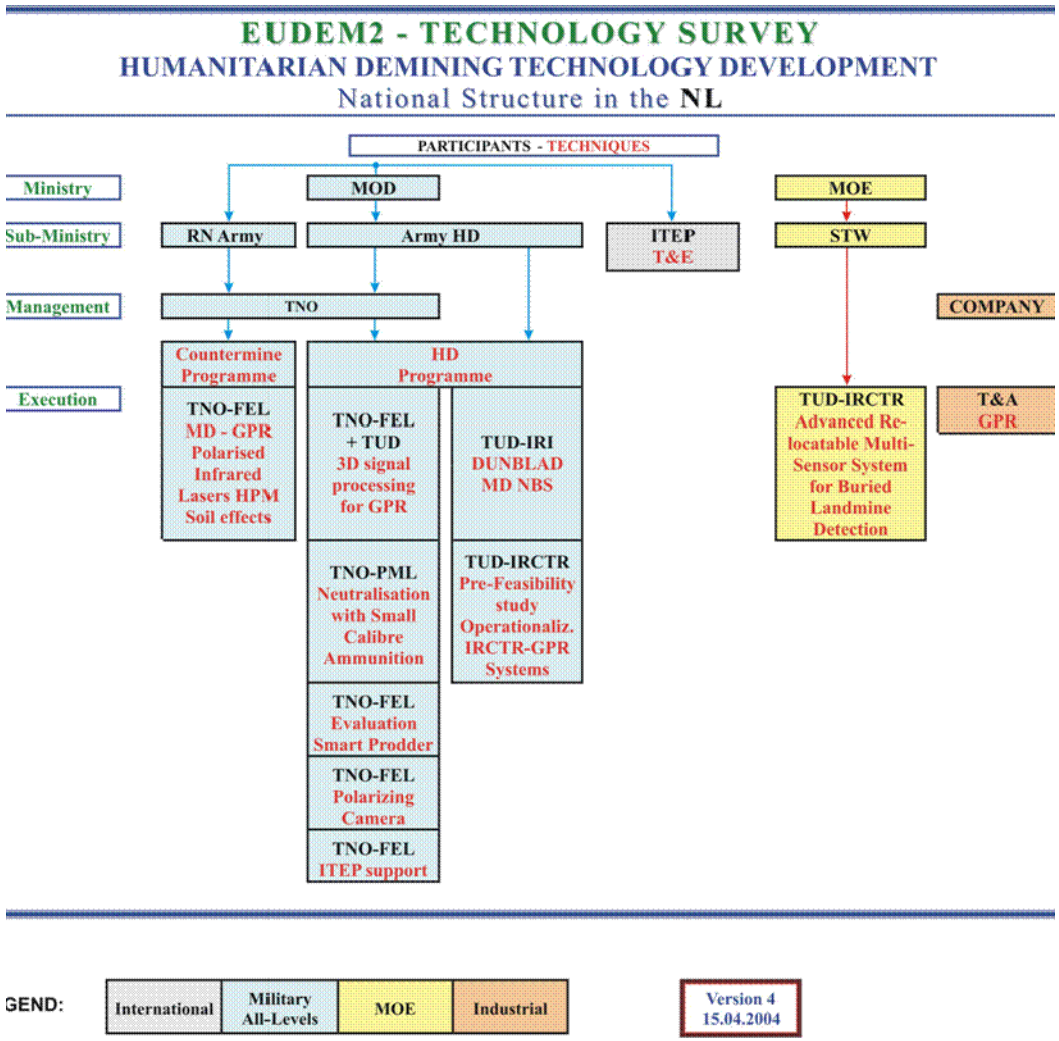


Figure 3-5 Overview of Dutch National Projects (abbreviations in Table 3-3)

AAMIS	Airborne Minefield (MF) Detection System
AMOS-M	MD-UXO Detector vehicle based
BAM	Federal Institute for Materials Research and Testing
BWB	Federal Office for Defence Technology and Procurement
CUTEC	Clausthaler Environment Technology Institute
DFG	German Research Foundation
DLR	German Aerospace Center
DNQR	Double Nuclear Quadrupole Resonance
EDT	Explosive Detection Technique
FEZ	Research and Development Centre
FGAN	Research Establishment for Applied Sciences
FHG	Fraunhofer Society (for Research)
FHR	Research Institute for High-Frequency Physics and Radar Technique (FGAN)
FMC	Federal Ministry of Commerce (BMWi)
FMER	Federal Ministry of Education and Research (BMBF)
FMOD	Federal Ministry of Defence (BMVg)
FOM	Research Institute for Optronic and Pattern Recognition (FGAN)
FZJ	Research Centre Juelich
GGA	Institute for Geo-scientific Common Tasks
GPR	Ground Penetrating RADAR
ICT	Institute for Chemical Technology (FHG)
IfZP	Institute for Non-destructive Testing (FHG)
IPA	Institute for Manufacturing Engineering and Automation (FHG)
IPK	Institute for Production Systems and Design Technology (FHG)
IR	Infra Red
IRFTRS	Institute of Radio Frequency Technology and Radar Systems (DLR)
KAMINA	EDT-System (electronic nose)
MAGNETO	Computer Aided UXO Survey System
MAG-SENSOR	Sophisticated Magnetic Field Sensor
MD	Metal Detector
MDD	Mine Detection Dog
MMSR	Mobile Mine search- and –Clearing System
MSMS	Multi-Sensor Mine Signature
MWR	Micro Wave Radiometer
NBS	Neutron Back-Scatter
NQR	Nuclear Quadrupole Resonance
PT-PFS	Project Funding Sub-Agency (of FMER)
T&E	Test and Evaluation
UWB	Ultra-Wide Band
UXO	Unexploded Ordnance
WIWEB	Bundeswehr Research Institute for Materials, Explosives, Fuels and Lubricants (BWB)
WS-STUDY	Workshop and Study
WTD	Defence Techniques Proving Ground (BWB)
X-Ray BS	X-Ray Back-Scatter

Table 3-1 Abbreviations used in Figure 3-3

BGS	British Geological Survey
CHA	Department of Conflict and Humanitarian Affairs (DFID)
DCMC	Dismounted Countermine Capabilities
DEODS	Defence Explosive Ordnance Disposal School
DFID	Department for International Development
DOE	Department of Education
DPA	Defence Procurement Agency
DSTL	Defence Science and Technology Laboratory
EDT	Explosive Detection Technique
EPSRC	Engineering and Physical Sciences Research Council
FCO	Foreign & Commonwealth Office
GPR	Ground Penetrating RADAR
HDTDP	Humanitarian Demining Technology Development Programme
IR	Infra Red
MAG	Mines Advisory Group
MCMC	Mounted Countermine Capability
MD	Metal Detector
MINDER CAP	Mine Detection Neutralisation and Route Marking - Competitive Assessment Phase
MITC	Mine Information Training Centre (MOD)
MOD	Ministry of Defence
MSMS	Multi-Sensor Mine Signature
NBS	Neutron Back-Scatter
NQR	Nuclear Quadrupole Resonance
PHMD	Portable Humanitarian Mine Detector
REMIDS	Remote Minefield Detection System (DERA)
T&E	Test and Evaluation
TME	Thales Missile Electronics (UK)
UK - CMF	United Kingdom Treasury Capital Modernisation Fund (inter-ministerial)
UWB - SAR	Ultra-Wideband Synthetic Aperture RADAR
UXO	Unexploded Ordnance

Table 3-2 Abbreviations used in Figure 3-4

DUNBLAD	Delft University Neutron Backscattering Landmine Detector
GPR	Ground Penetrating Radar
HD	Humanitarian Demining
HPM	?
ITEP	International Test and Evaluation Program for Humanitarian Demining
MD	Metal Detector
MOD	Ministry of Defence
MOE	Ministry of Education
NBS	Neutron Back-Scatter
RNl	Royal Netherlands
STW	Dutch Technology Foundation
T&A	T&A Survey
T&E	Test and Evaluation
TNO	Netherlands Defence Research Organisation
TNO-FEL	TNO-Physics and Electronics Laboratory
TNO-PML	TNO- Prins Maurits Laboratory
TUD-IRCTR	Delft University of Technology International Research Centre for Telecommunications-transmission and Radar
TUD-IRI	Delft University of Technology Interfaculty Reactor Institute

Table 3-3 Abbreviations used in Figure 3-5

4 Catalogue of Advanced Technologies for HD

Since 1994 considerable effort has been invested in order to develop technologies for landmine detection which could improve the productivity of present demining methods, while maintaining or increasing the deminers' safety.

There is perhaps a general disappointment that these technologies have not made a quick step from research and development to field use, which to a certain extent was based on understandable but unrealistic expectations. Nevertheless, a number of these technologies are now coming of age and test results do confirm that these technologies can increase the productivity of demining. Various development groups have repeatedly shown that this can be the case for the combination of metal detector with ground penetrating radar. The first combined metal detector and ground penetrating radar – the AN/PSS-14 (formerly HSTAMIDS) – has now been implemented into demining operations and others are expected to follow in the short-term.

In this *Catalogue*, we present the results of the most promising developments, and detailing technology which has now reached operational implementation stage, technology which is close to operational implementation, and prototype technology where further engineering investment is required before the technology could become operational, as well as technology which is still at a more applied research level.
The different technologies presented in the *Catalogue* are: *GPR*, *radiometer*, *nuclear quadrupole resonance* and *vapour/trace detection*. The individual systems are described in terms of the research programmes, the developers, the present specifications and available test results. Moreover, how to judge the readiness level of a technology has been defined as well.

Project Identification	
Project name **Acronym** **Participation Level** **Financed by** **Budget** **Start date** **End date**	**Contact Person** **Name** **First name** **Function** **email** **telephone** **fax** **Project Web Link**:
Project Description	
Involved Technology Related Activities	
Technology type **Readiness level** **Company/Institution**	
Detailed Description of the prototype/product	
Test & Evaluation	
Related Publications	

Figure 4-1 Technology Catalogue

Figure 4-1 shows the main information content of the *Catalogue*. EUDEM2 believes that the selection of systems featured in the *Catalogue* reflects the most promising technologies which may be implemented into mine action programs in a short, medium and long-term time frame.

The *Catalogue* is featured in the report “Catalogue of Advanced Technologies and Systems for Humanitarian Demining”.

5 Field Survey

After the EUDEM2 conference (September 2003), we noticed a lack of quantitative and qualitative analysis of technologies used in the field. EUDEM2, with the support of the University of Genova, Italy, planned a survey of minefield technology and practice aiming at providing "demining technology end-users need". The study has been conducted by visiting minefield sites and demining organizations, conducting several interviews and analyzing the collected data. The focus of the study has been technologies in use and operational aspects, including application/use conditions, costs, etc.

The study team has gathered information on the operational aspects of the technologies in field use and the requirements for new Machine technology, using a Survey Toolbox, including questionnaires and interviews specifically designed for the visited countries. The detailed methodology and the questionnaires are reported in *D19-Interviews Final Report*.

The "*Field Survey Results*" report presents the collected data, sorted by country, and its analysis. It is clear that attention has been paid to the analysis and comparison of data collected over different countries as there is no single mine problem and every situation is unique due to differences in the country's approach and type of region studied. The data collected through questionnaires has been analysed and presented in summary tables. The summary tables are aimed at providing readers with a schematic, easy and fast to read summarised picture of a country. Researchers and technology manufacturers will find in it a list of all technologies already available in the country, together with their application, running cost and general comments.
The structure of the Study Summary is schematically shown below, relative to a given country:

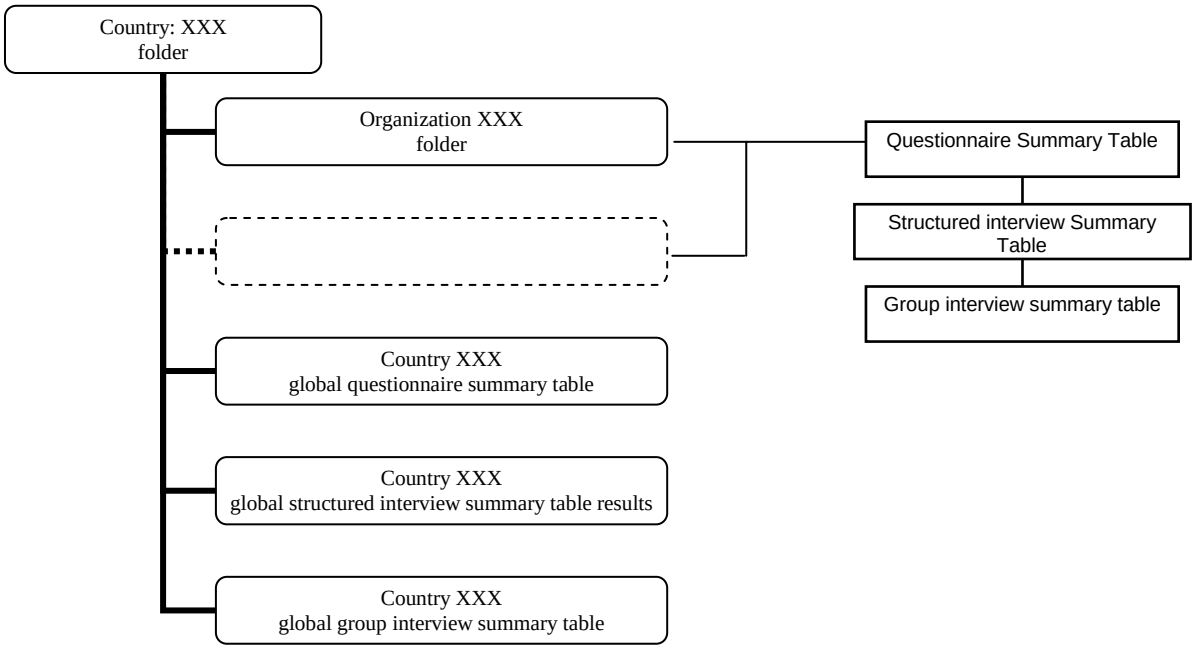


Figure 5-1 Field Study – summary structure

Moreover, a *Catalogue* of field technologies has been derived, "*Catalogue of Demining Technologies in Field Use*". Several categories have been considered: (1) Advanced Technologies (we call Advanced any technology beyond the ones already included in existing catalogues, whose technical specifications are not yet well known, such as Real Time Kinematic GPS), (2) Enhanced technologies (enhanced or adapted to local needs by end-users in the field) and (3) Tested technologies (tested in the field and not documented elsewhere).

6 Conclusion

The Technology Survey activity consisted in general terms in trying to provide services complementary to those offered by other mayor players e.g. GICHD releasing major studies, the work of ITEP, the release of the RAND Report, etc.

We tried our best to address relatively unexplored areas which we believed to be of interest for our target audience, the technology developers, and possibly beyond, including the development of the Technology *Catalogue*, the MD Patent Study, the analysis of R&D efforts in Central and Eastern Europe, the overview of EC co-sponsored projects and national research programmes, the soil studies and the field surveys. We did profit from some windows of opportunities, such as the enthusiasm of the University of Genoa, in the person of Emanuela Cepolina, which allowed carrying out an interesting and cost effective field study, or the collaboration request by GICHD on their manual clearance study.